Numerical Simulations of Sediment Transport and Scour around Mines

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LONG−TERM GOALS

The long term goal of this research is to understand and predict the scour and transport of submerged objects in coastal waters.

OBJECTIVES

The objective of this research is to verify a computational fluid dynamics (CFD) model for sediment transport and scour of mines in coastal waters with laboratory and field observations. The three−dimensional flow around and scour of partially and unburied mines in the coastal zone is being simulated with a numerical CFD model for both wave and current dominated conditions. The predicted flow, sediment transport and bed scour model is being verified with laboratory and field observations obtained by collaborators (PI Garcia, University of Illinois at Urbana−Champagne (UIUC); PI Richardson, Naval Research Lab; and PI Howd, University of South Florida).

APPROACH

In this research, we are modelling the three−dimensional flow field and sediment transport around submerged objects which have dimensions and characteristics similar to military mines. The FLOW−3D CFD software package is being used to solve for the flow, sediment transport, and evolution of the seabed around the mine under wave and current conditions specified at the boundaries of the numerical domain. FLOW−3D solves the nonlinear Navier−Stokes equations in three−dimensions, and uses the Volume−of−Fluid (VOF) method to track fluid−fluid or fluid−sediment interfaces (Hirt and Nichols, 1981). FLOW−3D also uses the Fractional Area/Volume Obstacle Representation (FAVOR) method to represent the complex boundaries containing the flow (Hirt and Sicilian, 1985). Using FAVOR, the boundaries of the domain (including any obstacles in the flow) can evolve in time and thus can be used to model the changes to the seafloor or to the position and orientation of obstacles, such as mines, within the flow field. FLOW−3D also allows for several turbulence closure schemes to be incorporated and tested. These closure schemes include simple eddy viscosity, one−dimensional Prandtl mixing length, two−equation $k-e$, large−eddy, and four−equation Re−Normalized Group (RNG) models.

The present module in FLOW−3D allows for the movement of sediment as a result of the shear stress exceeding the critical value required for incipient motion (developed to model the erosion of foam duct work in heat transfer problems). The deposition of sediment relies on the two−component drift

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14. ABSTRACT
The objective of this research is to verify a computational fluid dynamics (CFD) model for sediment transport and scour of mines in coastal waters with laboratory and field observations. The three??? dimensional flow around and scour of partially and unburied mines in the coastal zone is being simulated with a numerical CFD model for both wave and current dominated conditions.

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flux module in FLOW−3D (developed to model snowdrifts in air−snow interaction problems). We are evaluating this sediment transport module with continental shelf wave and mean current flows.

The model is initially being evaluated with laboratory observations of flow and scour around a cylinder. As more laboratory (PI Garcia, UIUC) and field (PI Griffin, OMNI Tech. and PI Howd, USF) observations become available, we will evaluate the model with realistic mine geometries and non−uniform seabed topography with bedforms. The model results will be used to identify the tendency of a mine to scour or be buried, and provide guidance on the general behavioral characteristics of mines under various flow conditions.

WORK COMPLETED

We (master's student H. Smith and PI) have investigated the model's ability to simulate the flow around a cylindrical obstacle and 5 scoured bed profiles (Smith and Foster, 2002a). We have evaluated the model's ability to resolve the two dimensional scour around a cylindrical object (Smith and Foster, 2002b). We have also performed three−dimensional simulations of the flow around a cylindrical mine.

RESULTS

The model has been used to simulate the two−dimensional flow around a submerged cylinder which is suspended over 5 different bed profiles. The different profiles represent 5 quasi−steady scour profiles as used in the laboratory experiments of Jensen et al., 1990. These laboratory experiments present mean velocity data and bed velocity data, which are used for model verification. Model and laboratory data comparisons for mean vertical and horizontal velocity are favorable, with root−mean−squared deviations averaging 3.24 cm/s for the mean horizontal velocities and 1.19 cm/s for the mean vertical velocities. Figure 1 shows the vector comparisons for the modelled and observed velocities.

Figure 2 shows the bed velocity comparisons for the five profiles. The comparisons between model and data show that the model under−predicts the bed velocities underneath the cylinder (x=50 cm) in Profile 2. This might lead to an under−prediction of the scour in this area and/or a longer time scale for development into Profile 3. Profile 3 shows over−predicted bed velocities in the front part of the scour hole, under−predicted velocities in the scour hole behind the center of the cylinder, and over−predicted velocities in the wake of the scour dune. This may result in a deeper front of the scour hole, a larger dune in the wake of the cylinder, and greater downstream erosion. Profile 4 generally shows under−predicted velocities for the entire domain, which would suggest a longer time scale to reach equilibrium. Figure 5 shows an over−prediction of bed velocities in the scour hole, indicating the model predicted scour would have not reached equilibrium at this stage.

Results for the scour simulations are shown in Figure 3. Please note, the time scales for the model and laboratory data are significantly different, and are given at the top of of each panel. In several cases, the general shape and size of the scour hole match the results from the laboratory data reasonably well. However, the model tends to scour upstream more than what the laboratory data shows. This is inconsistent with the hydrodynamic simulations where the bed velocities were under−predicted upstream of the cylinder and is indicative of potential limitations of the assumed input parameter values. The equilibrium profile (bottom panel) shows reasonable agreement in the final depth of the scour hole. However, the length of the hole is much larger, and there is a larger dune downstream of the hole. This is consistent with the modelled bed velocities, as there is an over−prediction of the bed velocities in the hole and an under−prediction downstream of the scour hole. In this case, the limiting factor may be the hydrodynamic simulation.

Three−dimensional simulations of the flow around a cylindrical mines have shown near bed flow patterns consistent with qualitative observations of the scour of cylindrical objects. Figure 4 shows the near bed flow patterns and bed stress resulting from a transversely approaching flow. The simulations are consistent with previous qualitative observations and indicate scour will initiate at the mine ends. These results leave us encouraged that future investigations will continue to provide insight into the dominant physics involved in the object scour process.

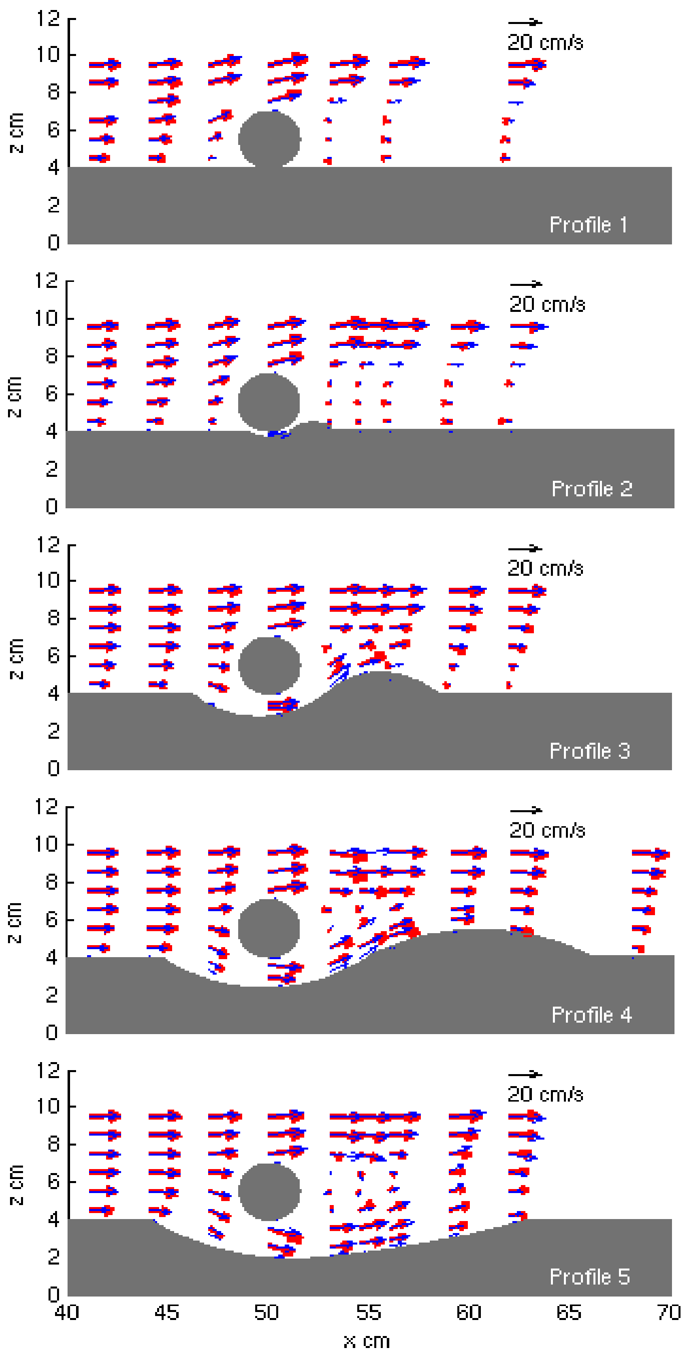

Figure 1. Model−Data velocity vector comparisons. The red vectors represent the laboratory data obtained by B.L. Jensen et. al. (1990). The blue vectors represent the model data. Each panel represents a different profile in the time evolution of the scour hole. The top panel (Profile 1) is the initial profile, while the bottom panel (Profile 5) represents the equilibrium profile.

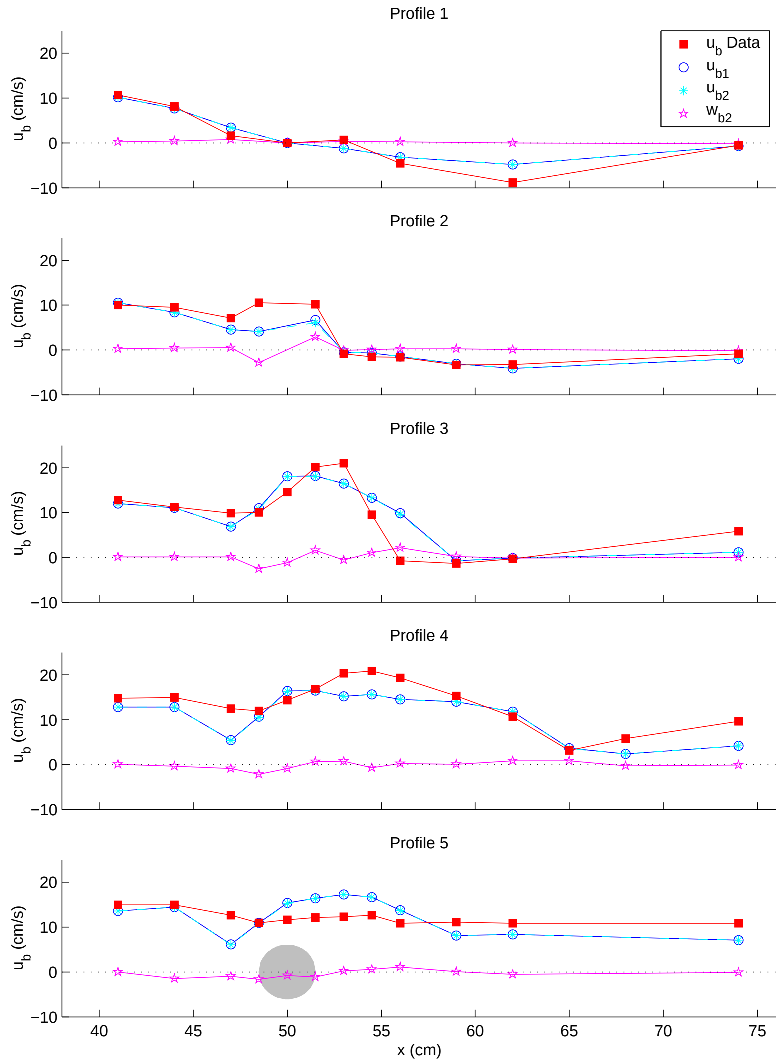

Figure 2. The bed velocities (0.5 cm above bed) for all five profiles given in Figure 1. The squares represent the laboratory data. The circles and asterisks represent the modelled bed velocities calculated with two different methods. The stars represent the vertical bed velocities for the rotation method.

IMPACT/APPLICATIONS

This work is relevant to society and ONR's objectives in two ways. First, current models for predicting the scour of submerged objects rely heavily on empirical models based on existing laboratory observations in idealized conditions and not in natural environments. This investigation will further our understanding of the dominant physics at the fluid−sediment interface. Secondly, these results should improve our ability to predict the scour of mines, bridge piers, and other submerged objects present on the sea floor in the coastal environments

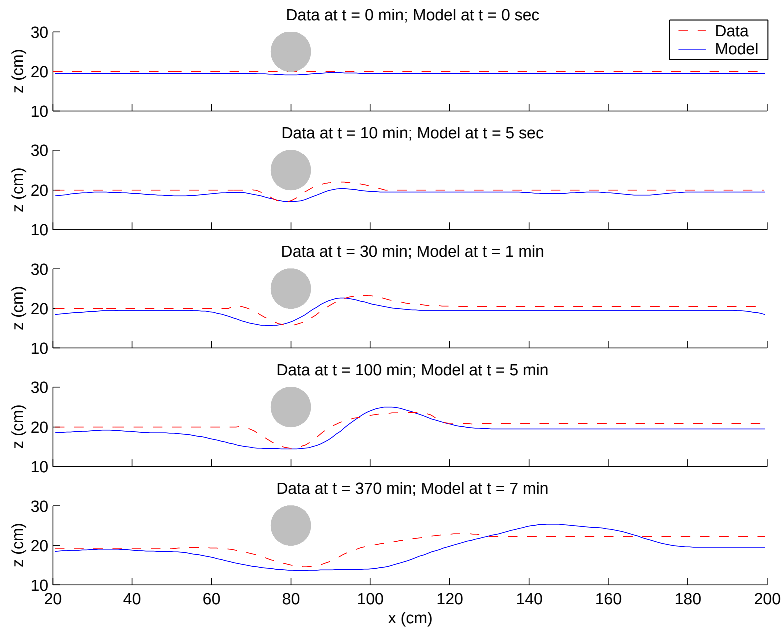

Figure 3. Bed Scour Comparisons
The comparison of predicted (—) and observed (- -) bed profile at 5 times following the onset of scour.

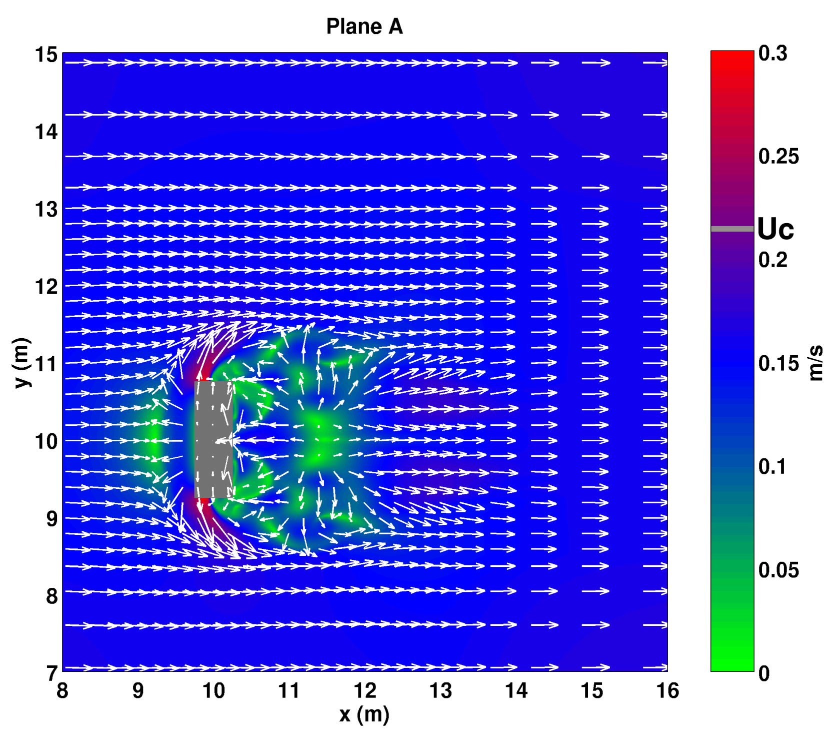

Figure 4. Near bed velocity predictions of a transversely approaching current show high velocities at the mine ends. The color intensity represent velocity magnitudes. Scour will be initiated for velocity magnitudes over 0.21 m/s.

RELATED PROJECTS

The model developed here will ultimately be compared with laboratory and field observations obtained by collaborators (PI Garcia, University of Illinois at Urbana−Champagne (UIUC); PI Richardson, Naval Research Lab; PI Griffin, OMNI Technologies; and PI Howd, University of South Florida). This project will also benefit from current and future scientific exchanges with the Danish Technical University (PI's Fredsoe and Sumer).

REFERENCES

Hirt, C. W. and B. D. Nichols (1981) "Volume of Fluid (VOF) Method for the Dynamics of Free Boundaries." *J. Comp. Physics*, 39.

Hirt C. W. and Sicilian, 1985, "A Porosity Technique for the Definition of Obstacles in Rectangular Cell Meshes," *Proc. 4th Intern. Conf. Ship Hydro.*,Washington, DC.

Jensen, B. L., B. M. Sumer, H. R. Jensen, J. Fredsoe (1990). "Flow around and forces on a pipeline near a scoured bed in a steady current." *Journal of Offshore Mechanics and Artic Engineering.* Vol. 112.

PUBLICATIONS

Smith, H.D. and Foster, D.L. (2002). "Modeling of Flow Around a Cylinder Over a Scoured Bed." *Journal of Waterway, Port, Coastal and Ocean Engineering,* in review.

Smith, H.D. and Foster, D.L. (2002). "Modelling of Flow and Scour Around a Pipeline." I*n Proceeding of the 28th International Conference of Coasta*l *Engineering*. Cardiff, Wales, in press.